AD NUMBER

AD808673

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; NOV 1966. Other requests shall be referred to Air Force Aero Propulsion Lab., Research and Technology Div., Wright-Patterson AFB, OH 45433.

AUTHORITY

Air Force Aero Propulsion Lab ltr dtd 12 Apr 1972

AD808673

LUBRICITY OF JET FUELS

NOTICE

NOT RELEASABLE TO OTS

Qualified users may obtain copies of this report from the Defense Documentation Center.

The distribution of this report is limited because it contains information of possible application to future weapon systems and consequently is not considered of general interest to the public scientific and technical community.

This document may not be reproduced or published in any form in whole or part without prior approval of the Government. Since this is a progress report, the information herein is tentative and subject to changes, corrections, and modifications.

LUBRICITY PROPERTIES

OF

HIGH-TEMPERATURE

JET FUELS

J. K. Appeldoorn
F. F. Tao

Esso Research and Engineering Co.
Products Research Division
Linden, New Jersey

QUARTERLY REPORT NO. 6

15 AUGUST - 15 NOVEMBER, 1966

CONTRACT NO. AF33 (615) 2828

FOR

Air Force Aero Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

TABLE OF CONTENTS

FOREWORD

This report was prepared by the Advanced Lubrication Project, Products Research Division, Esso Research and Engineering Company at Linden, New Jersey under Contract AF33 (615) 2828. This program is administered by the Air Force Aero Propulsion Laboratory, Research and Technology Division, Air Force Systems Command with Arthur F. Levenstein, 1/LT, USAF as coordinator.

This report covers work conducted from 15 August to 15 November, 1966.

ABSTRACT

Humidity is as important as dissolved oxygen in its effect on friction and wear. For most pure hydrocarbons and all the commercial fuels, wear and friction increase with oxygen and moisture content, indicating that corrosive wear is the controlling mode of wear. Methyl naphthalene behaves anomalously. It gives very high wear and friction in a dry inert atmosphere. Both oxygen and water greatly reduce this wear.

Differences among fuels are accentuated by high oxygen content, high humidity, high loads and high temperatures. In an inert atmosphere the effect of humidity, load and temperature is greatly diminished, and the difference among fuels is much less.

Antioxidant additives do not appear to affect friction and wear. Lubricity additives such as oleic acid are effective in reducing corrosive wear but not elsewhere. Oleic acid does not reduce the wear of methyl naphthalene under any conditions.

Work in the immediate future will continue to investigate the complex interaction between fuel composition, atmosphere and temperature.

I. INTRODUCTION

In previous work under this Contract, several important facts have been uncovered:

- Jet fuels differ in their lubricity characteristics. The high degree of refining necessary for good thermal stability generally leads to a fuel with poor lubricity. These "squeaky-clean" fuels can cause serious field problems.

- The fuel components responsible for good lubricity are high molecular weight aromatics. Other components such as sulfur and nitrogen compounds have little effect.

- Small amounts of corrosion inhibitors or specific lubricity additives can improve lubricity markedly, even at concentrations as low as 10 ppm.

In the last Quarterly Report some preliminary findings were presented on the effect of temperature and surrounding atmosphere. The effect of temperature was relatively minor, most of the effect being the reduction of viscosity at higher temperatures. The surrounding atmosphere, however, was found to be extremely important. Dissolved oxygen is a strong pro-wear agent in typical jet fuels and wear can be greatly reduced if tests are run under a blanket of an inert gas. In addition, synergistic effects were found for fuels containing both aromatics and paraffinics and there is a pronounced interaction between fuel composition and oxygen availability.

The work presented in this report is largely confined to broadening our understanding of the effect of oxygen and also water vapor on friction and wear, how this is influenced by fuel composition, and the overall effect of temperature on all of this.

II. EFFECT OF FUEL VARIABLES AND ENVIRONMENT

A. Effect of Fuel Composition

In the previous Report, it was shown in the four-ball test that there was an interesting synergistic effect between the isoparaffinic Bayol 35 and the heavy aromatic methylnaphthalene. Small amounts of either component in the other would bring about a marked reduction in wear. The optimum mixture appeared to be about 30% methylnaphthalene in 70% Bayol 35.

These tests were repeated using the ball-on-cylinder apparatus. The same results were obtained as shown in Figure 1. At this time, it was found that the redistilled methylnaphthalene, which was known to contain both the 1-methyl and 2-methyl isomers in about equal amounts, also contained about 5% of a third component, and that the sulfur content was 0.86%. The third component is evidently a sulfur compound, probably a thiophene, boiling very close to the methylnaphthalene, and perhaps forming an azeotrope. A sample of "high purity" 1-methylnaphthalene was therefore purchased and tested in 30% concentration in Bayol 35. The result, also shown in Figure 1, is a check of the previous result. However, this sample of 1-methylnaphthalene also had an impurity, for it analyzed at 0.39% S. There is some question, therefore, whether this sulfur compound might be causing some of the effects found for methylnaphthalene. It is our opinion, however, that this sulfur compound is not the active component. Data reported previously indicated no sulfur compound to be this active, and we believe the effect is purely one of heavy aromatics. However, this will be studied further.

Figure 1 also shows the friction values, which were not measured in the four-ball test. Unlike the wear results, no synergism was found. Friction was highest with Bayol 35 and lowest with methylnaphthalene, with no minimum in the curve.

B. Effect of Dissolved Water

Earlier tests had shown that oxygen increases wear by a corrosion process, the resultant wear particles being largely FeO. It would therefore be likely that this corrosion would be accelerated by the presence of dissolved water. This was first confirmed by a series of four-ball wear tests run in air, using heptane as the test liquid. In these tests, a layer of liquid water was put in the bottom of the test cup. This insured that the heptane was saturated with water throughout the test.

The effect of this dissolved water is shown in Figure 2. The wear scar diameter increased by 40%, corresponding to an increase in wear rate (grams/minute) of 4-fold.

This result made it obvious that the relative humidity of the atmosphere around the test is a very important variable. The amount of water that will dissolve can be expected to depend on the partial pressure (i.e., the humidity) of the surrounding atmosphere.

To confirm this, another series of four-ball tests were run in [illegible] th 0% and 100% humidity, in both the presence and absence of oxygen. The [illegible] fuels were Bayol 35, methylnaphthalene, and a 70/30 mixture of the two. Data [illegible] ented in the previous Report had shown these two fuels to behave quite different [illegible] toward oxygen: Bayol 35, an isoparaffinic fuel, gave low wear in the absence of oxygen and increasing

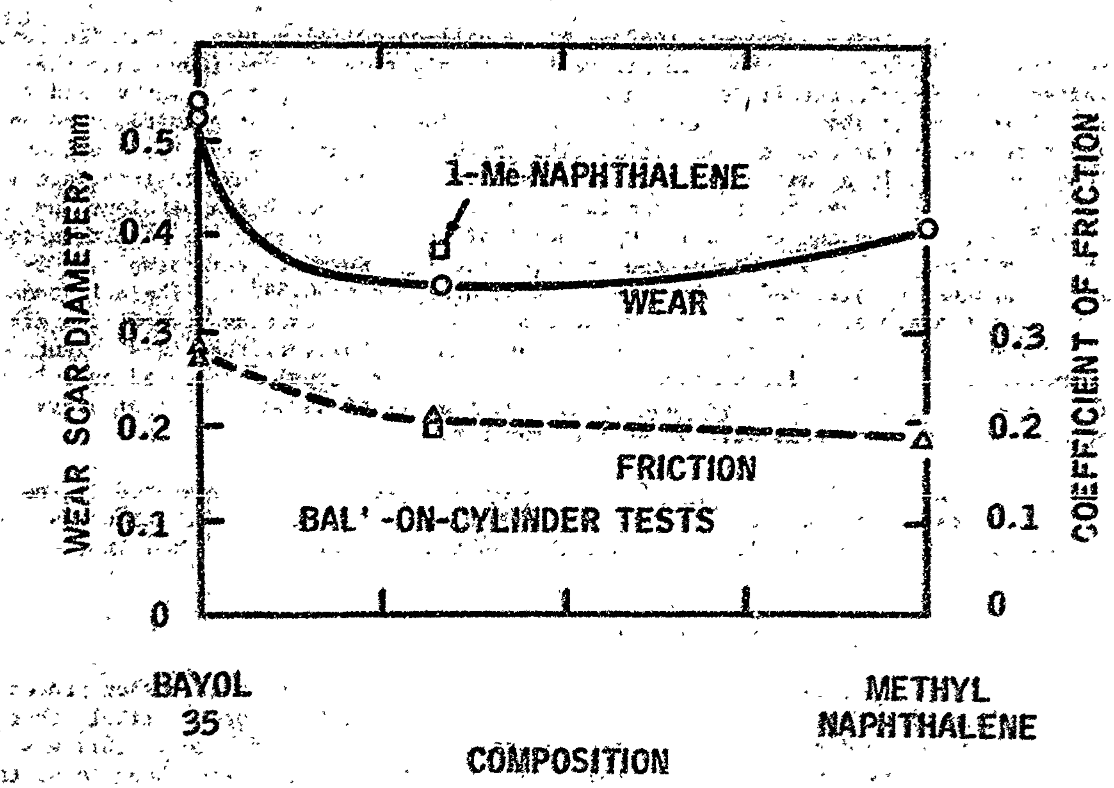


FIGURE 1 - EFFECT OF HYDROCARBON COMPOSITION ON FRICTION AND WEAR IN BALL-ON-CYLINDER TEST

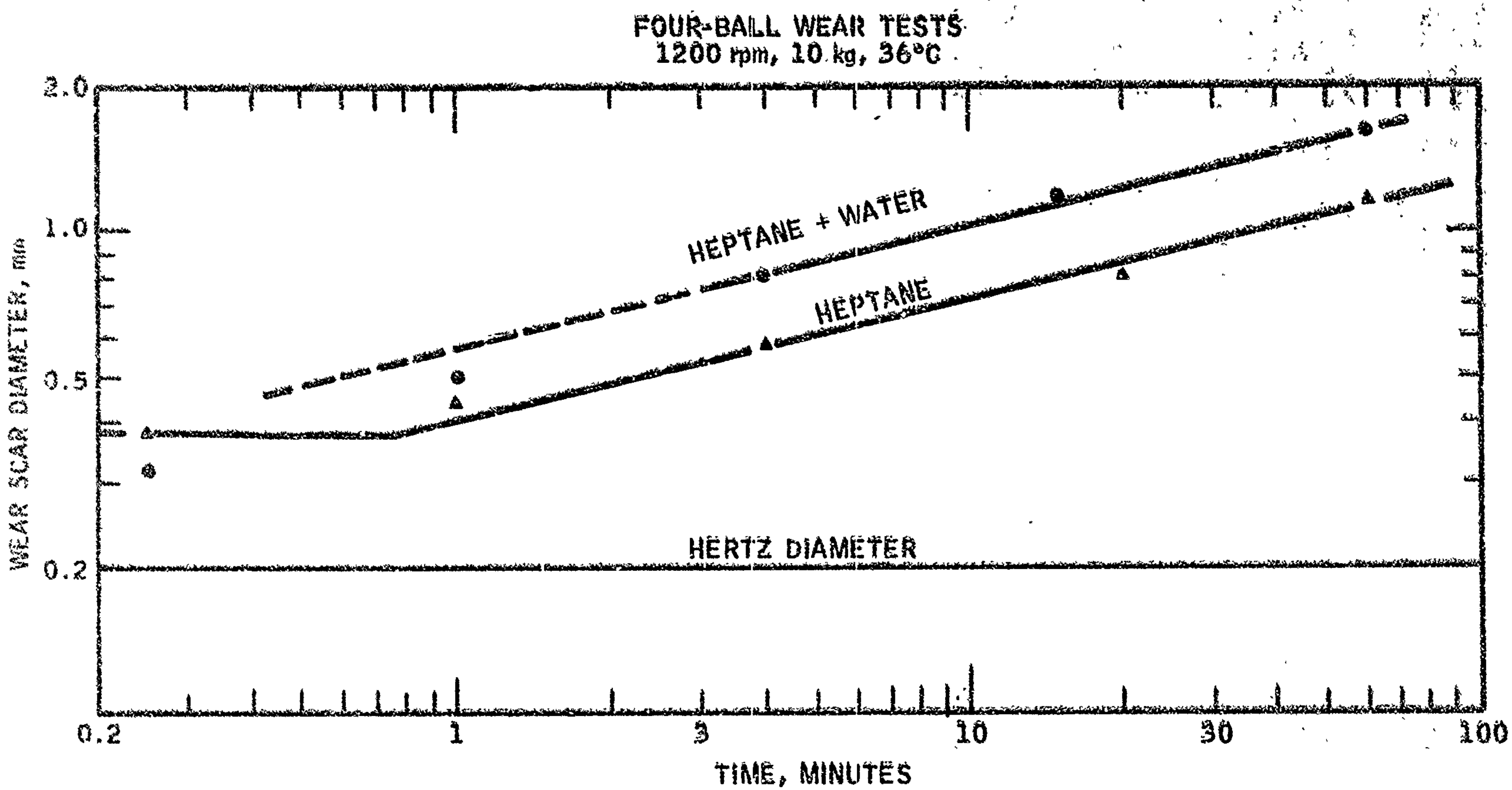


FIGURE 2 - WATER INCREASES WEAR RATE OF HEPTANE IN FOUR-BALL TEST

wear as the oxygen content increased. Methylnaphthalene, on the other hand, gave extremely high wear in the absence of oxygen, indicating an entirely different mode of wear. The 70/30 mixture gave lower wear than either pure component and this was true both in the presence and absence of oxygen.

These tests were all run with the plastic collar around the test cup, and the controlled atmosphere bled in continuously. Conditions of 100% R.H. were obtained simply by bubbling the gas (air or argon) through water. Dry conditions (0% RH) were obtained with argon (99.995% Ar) by using it directly from the gas cylinder, where it is completely anhydrous. This was also done with cylinder air, although in some of the earlier tests, ordinary compressed air was passed through a desiccant instead.

The effect of dissolved water is shown in Figures 3 and 4. Figure 3 gives the data in air. The effect of humidity is to increase the wear of Bayol 35, but to decrease the wear of methylnaphthalene. Figure 4 gives the data in argon. Under humid conditions, the differences in behavior between the different fuels is completely wiped out: The catastrophic wear of methylnaphthalene in dry argon disappears. So does the synergistic effect of mixtures of Bayol 35 and methylnaphthalene. Thus, in the absence of oxygen, water is the great equalizer. But in the presence of oxygen, water may either increase or decrease wear, depending on fuel composition.

C. Effect of Dissolved Water and Oxygen With Commercial Fuels

Because of the importance of both oxygen and water vapor in the surrounding atmosphere, it was decided to evaluate the commercial jet fuels under the four combinations of wet air, dry air, wet argon, and dry argon. Previous data had been obtained in room air--21% oxygen and uncontrolled humidity.

Five commercial fuels were chosen (PW-523, RAF-164-64, JP-4, JP-5, and Bayol 35) at 160F and were run at various loads of 240g, 480g, and 1000g. These tests were carried out in the modified ball-on-cylinder rig with an enclosed fuel-circulating system under the same four atmospheres: dry air, wet air, dry argon, wet argon. The wet air and wet argon were very close to 100% relative humidity according to readings of dry and wet bulb temperatures.

The test results are shown in Table 1 and the wear scar diameters versus loads are plotted in Figures 5 through 9. Several common friction and wear phenomena among these fuels are noteworthy: (1) friction and wear are higher in air than in argon for both dry and wet conditions; (2) friction and wear in argon are not only lower but also less dependent on load than in air, so that the difference of friction and wear in air and argon is more evident at higher loads; (3) wear in wet air is higher than in dry air, (4) the difference in friction and wear in dry and wet argon is rather small, indicating that moisture may not be detrimental in an inert atmosphere and (5) metallic contact appears generally lower in air than in argon. It seems that the oxide film is continuously formed and is taken off in sliding contact. The continuous removal of the oxide film by rubbing is the probable cause of higher wear in an oxidizing atmosphere despite its lower metallic contact.

These results again showed that the highly-refined fuels give higher wear than other commercial fuels in air: in wet air, PW-523 and Bayol 35 gave appreciably higher wear than other fuels, both at 480g and 1000g, in dry air, PW-523 consistently gave higher wear at all loads. In argon, the highly-refined fuels did not appear to be inferior to other fuels. On the contrary, JP-5 and RAF-176-64 gave slightly higher wear than the other two fuels in wet argon at 1000g load. This

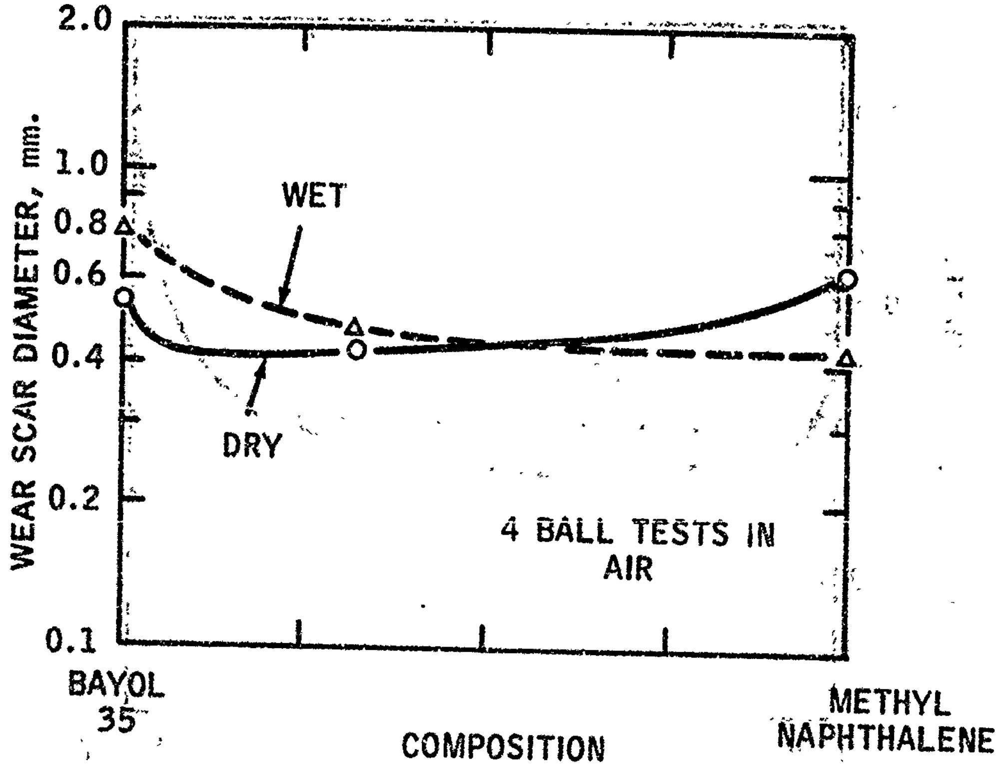


FIGURE 3 - EFFECT OF HUMIDITY IN AIR ON WEAR IN FOUR-BALL TEST

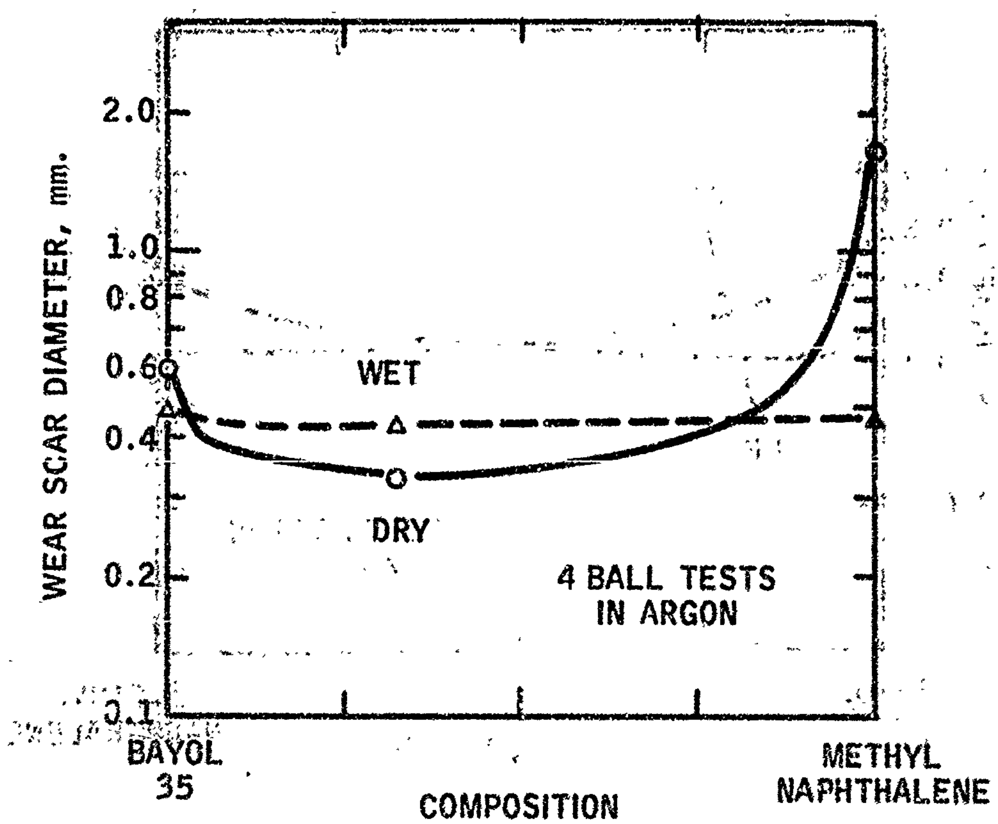


FIGURE 4 - EFFECT OF HUMIDITY IN ARGON ON WEAR IN FOUR-BALL TEST

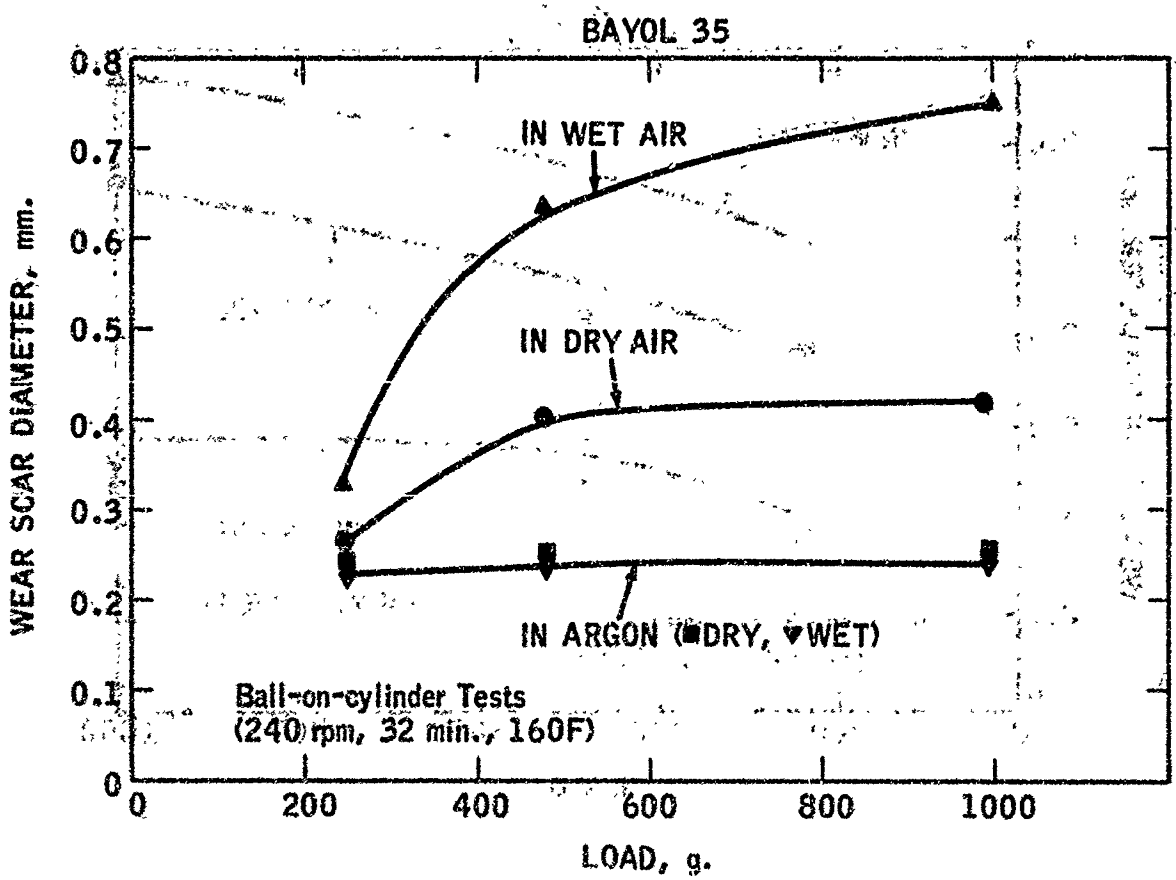


FIGURE 3 - EFFECT OF ATMOSPHERE ON WEAR OF BAYOL 35

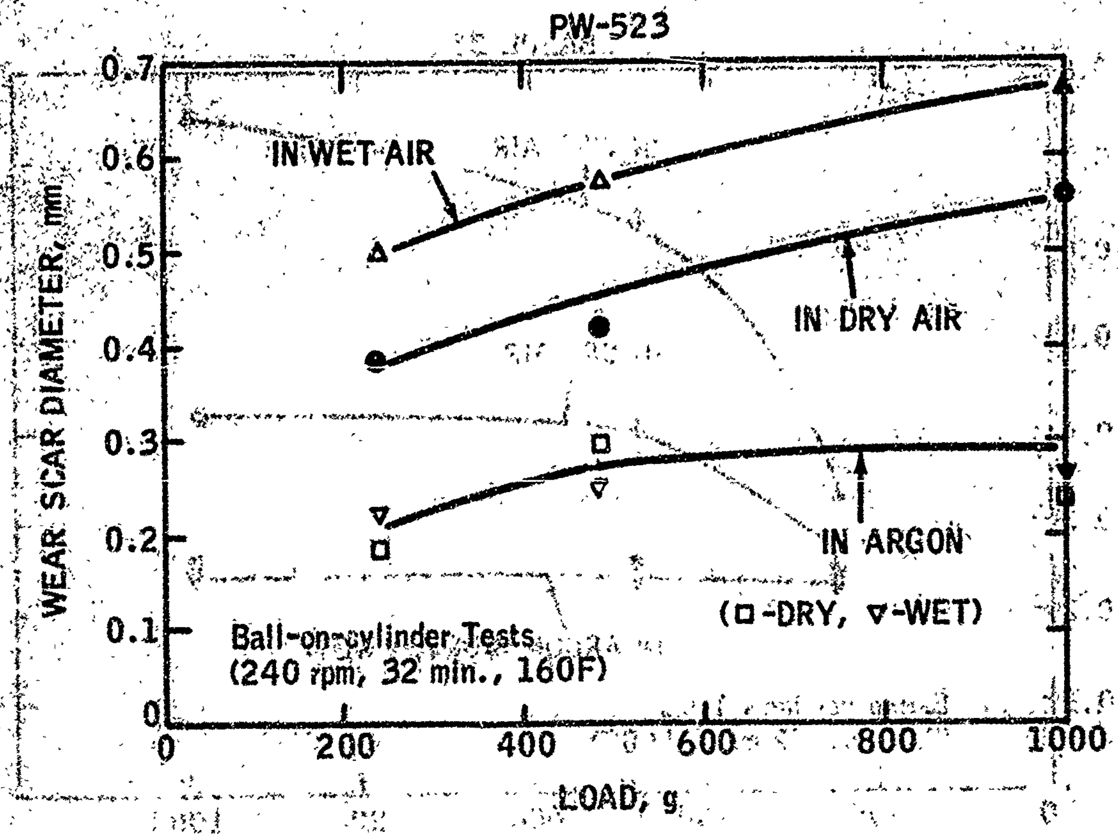


FIGURE 6 - EFFECT OF ATMOSPHERE ON WEAR OF PW-523

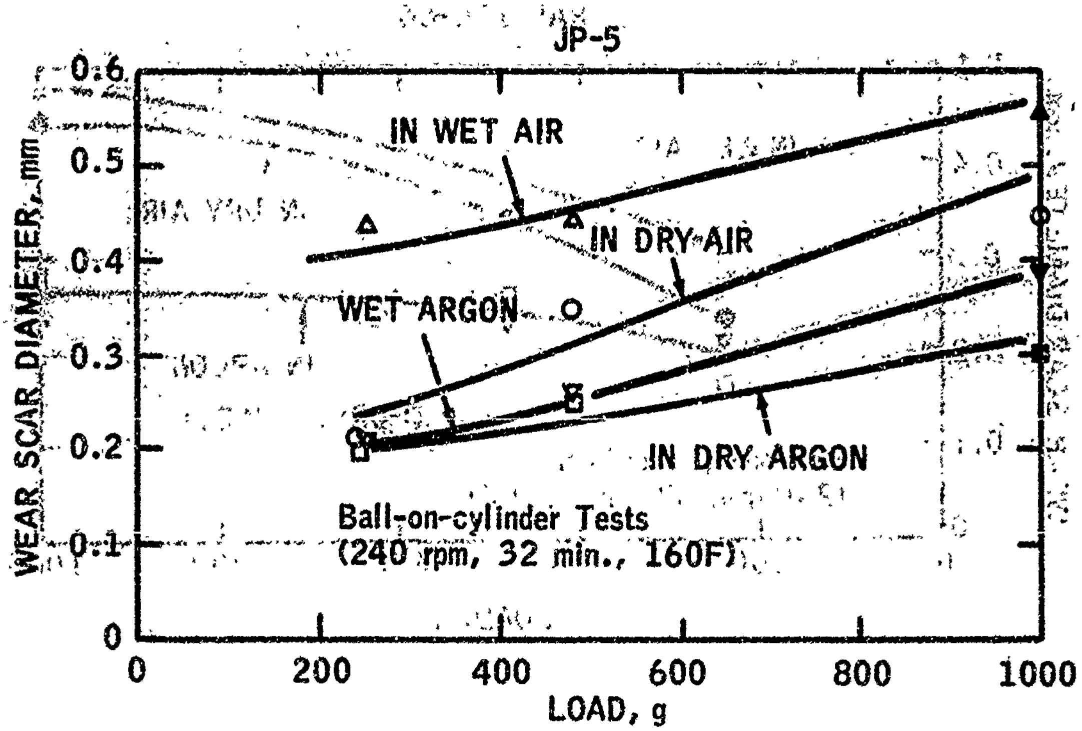


FIGURE 7 - EFFECT OF ATMOSPHERE ON WEAR OF JP-5

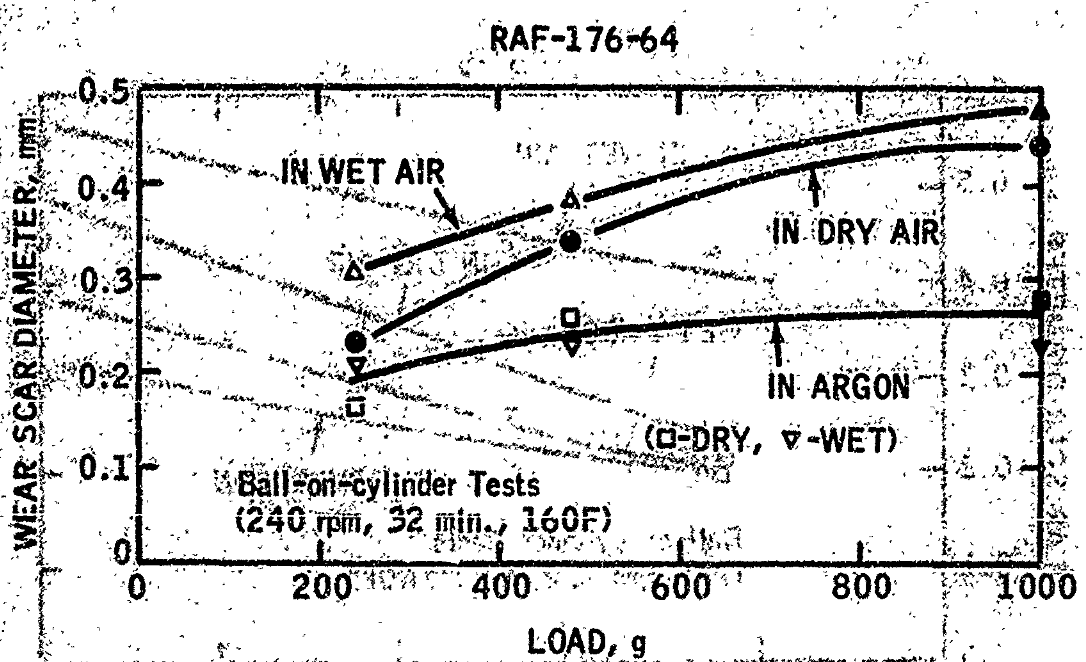


FIGURE 8 - EFFECT OF ATMOSPHERE ON WEAR OF RAF-176-64

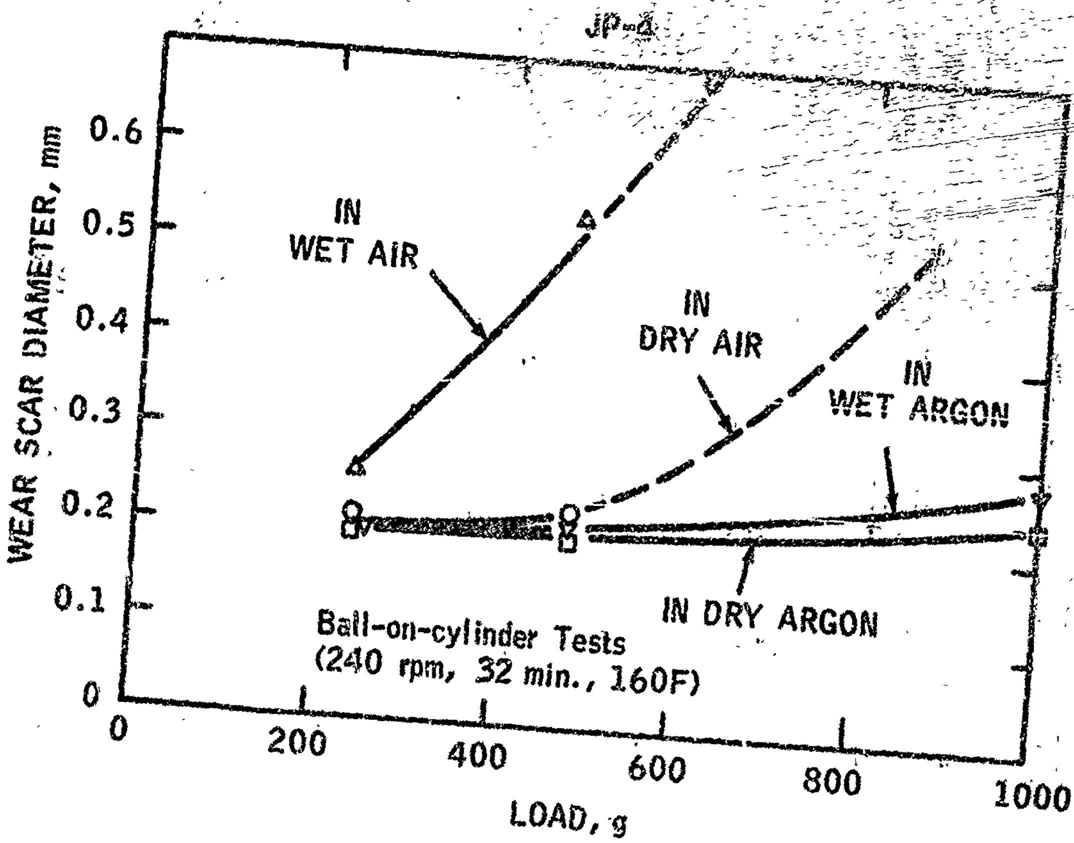


FIGURE 9 - EFFECT OF ATMOSPHERE ON WEAR OF JP-8

TABLE 1

FRICTION AND WEAR OF COMMERCIAL FUELS IN VARIOUS ATMOSPHERES

Ball-On-Cylinder Tests (160°F, 240 rpm, 32 min)

	1000 gm Load				480 gm Load				240 gm Load			
	In Air		In Ar		In Air		In Ar		In Air		In Ar	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Bayol 35												
Vis 1.04 cp												
Wear Scar, mm	0.41	0.75	0.25	0.24	0.40	0.63	0.24	0.23	0.26	0.33	0.24	0.23
Coef. of Friction	0.14	0.28(a)	0.17	0.18	0.19	0.13	0.15	0.12	0.14	0.12	0.13	0.10
% Metallic Contact	80.6	100	100	100	88.7	100	100	100	43.4	81.1	93.8	98.2
JP-5												
Vis 0.74 cp												
Wear Scar, mm	0.44	0.56	0.30	0.39	0.35	0.44	0.25	0.25	0.21	0.44	0.20	0.21
Coef. of Friction	0.60(a)	0.32(c)	0.19	0.17	0.23	0.18	0.14	0.15	0.32	0.21	0.14	0.16
% Metallic Contact	94.8	100	100	100	88.1	88	100	99.7	63.9	90.2	98.3	99.2
NAF-176-64												
Vis 0.68 cp												
Wear Scar, mm	0.44	0.48	0.28	0.33	0.34	0.38	0.26	0.23	0.23	0.31	0.17	0.21
Coef. of Friction	-- (a)	0.15(a)	0.12	0.14	0.15	0.16	0.12	0.12	0.20	0.12	0.06	0.12
% Metallic Contact	100	100	99.4	100	98.1	95.1	100	100	80.5	93.4	30	100
PW 523												
Vis 0.74 cp												
Wear Scar, mm	0.56	0.67	0.24	0.27	0.42	0.58	0.30	0.25	0.39	0.50	0.19	0.22
Coef. of Friction	0.38(a)	0.30(a)	0.13(b)	0.15(b)	0.11	0.19	0.15(b)	0.16(b)	0.11	0.27	0.19(b)	0.19(b)
% Metallic Contact	80.9	100	100	100	12.1	96	96.4	100	0	94	95.2	100
JP-6 (at 120°F)												
Vis 0.42 cp												
Wear Scar, mm	(c)	(c)	0.24	0.28	0.22	0.54	0.20	0.21	0.21	0.26	0.20	0.20
Coef. of Friction	(c)	(c)	0.13	0.17	0.14	0.17	0.12	0.15	0.11	0.12	0.12	0.15
% Metallic Contact	(c)	(c)	100	100	90.2	97.3	100	100	89.4	90.1	98.3	100

Notes:

(a) Friction trace erratic.
(b) A defect of the spring was found after tests; friction readings may be in some error.
(c) Tests discontinued due to the scuffing..

FYT:lmm
12/11/66

difference, although not highly significant, is rather anomalous. JP-4, which has a lower viscosity than the other fuels, could not be run at 1000g in air because of excessive friction. At lower loads, it gave fairly low wear and friction.

A series of tests was also made on Bayol 35 at 1000g and 160F in dry air, room air, and air saturated with moisture, to evaluate the effect of an intermediate moisture content on friction and wear. The results, given in Table 2, show that friction and wear in dry air and in humid air are certainly different and that 26% RH (room air) has about the same effect as 100% RH.

D. Effect of Temperature

Four-ball data reported earlier had shown some effect for temperature, particularly for the poor-lubricity fuels. It also appeared desirable to find if there was an interaction between temperature and atmosphere. These tests have been extended to the ball-on-cylinder rig and the Vickers pump.

1. Four-Ball Tests

A preliminary series of runs was made in the four-ball tester to see if corrosive wear is unusually temperature-sensitive. Bayol 35 in room air is known to give corrosive wear. Therefore, it was tested at temperatures from 36C (97F) to 125C (257F). The results are given in the table below.

Effect of Temperature on Wear

Bayol 35 in Room Air

(4-Ball Tests, 1200 rpm, 36C, 10 kg, 15 min)

Temperature, °C	Wear Scar Diameter, mm
36	0.67
68	0.74
99	0.73
125	0.76

It can be seen that wear increases somewhat with temperature, but the increase is, if anything, less than expected. The four-ball tester does not seem to be very sensitive under these conditions.

2. Ball-on-Cylinder Tests

The ball-on-cylinder device shows a considerably greater sensitivity to temperature. Tests were run on Bayol 35 at various loads at 240F. The results are tabulated in Table 3 together with those obtained from tests are 160F and 87F previously reported. In an inert atmosphere, friction and wear showed only a minor dependance on temperature. However, in air the effects were pronounced. For the 480g load, both friction and wear at 240F were double than at 160F. at 240F and 1000g load, the friction was so excessive the test had to be terminated.

The effect of temperature is even more striking when plotted at different concentrations of dissolved oxygen as in Figure 10. Wear scar diameters were 2-3 times higher at 240F than at 160F. Friction data are given in Table 4.

TABLE 2

EFFECT OF ATMOSPHERIC MOISTURE ON WEAR OF BAYOL 35

Ball-on-Cylinder Tests (1000 gm Load, 240 rpm, 160°F., 32 min.)

Atmosphere	% RH	Coef. of Friction	Wear Scar Dia., mm
Argon	0	0.13	0.28
Dry Air	0	0.14	0.41
Open Air	26	0.24*	0.59
Wet Air	100	0.23*	0.65

* Friction trace very erratic.

TABLE 3

EFFECT OF TEMPERATURE ON FRICTION AND WEAR OF BAYOL 35

Ball-On-Cylinder Tests (240 rpm, 32 min)

	1000 gm Load		480 gm Load		240 gm Load	
	In Air*	In N_2*	In Air*	In N_2*	In Air*	In N_2*
Wear Scar, mm						
@ 87°F	0.55	0.25	0.30	0.20	0.28	0.19
@ 160°F	0.57	0.25	0.34	0.24	0.30	0.24
@ 240°F	--	0.26	0.55	0.29	0.29	0.22
Coefficient of Friction						
@ 87°F	0.15	0.13	0.14	0.13	0.12	0.12
@ 160°F	0.27**	0.13	0.16**	0.15	0.15**	0.13
@ 240°F	--	0.12	0.32**	0.11	0.14**	0.13

Notes:

* In Air - In open air (in equilibrium with atmospheric moisture).
In N_2 - 87°F and 160°F runs in N_2, 240°F runs in Argon.

** Friction trace erratic.

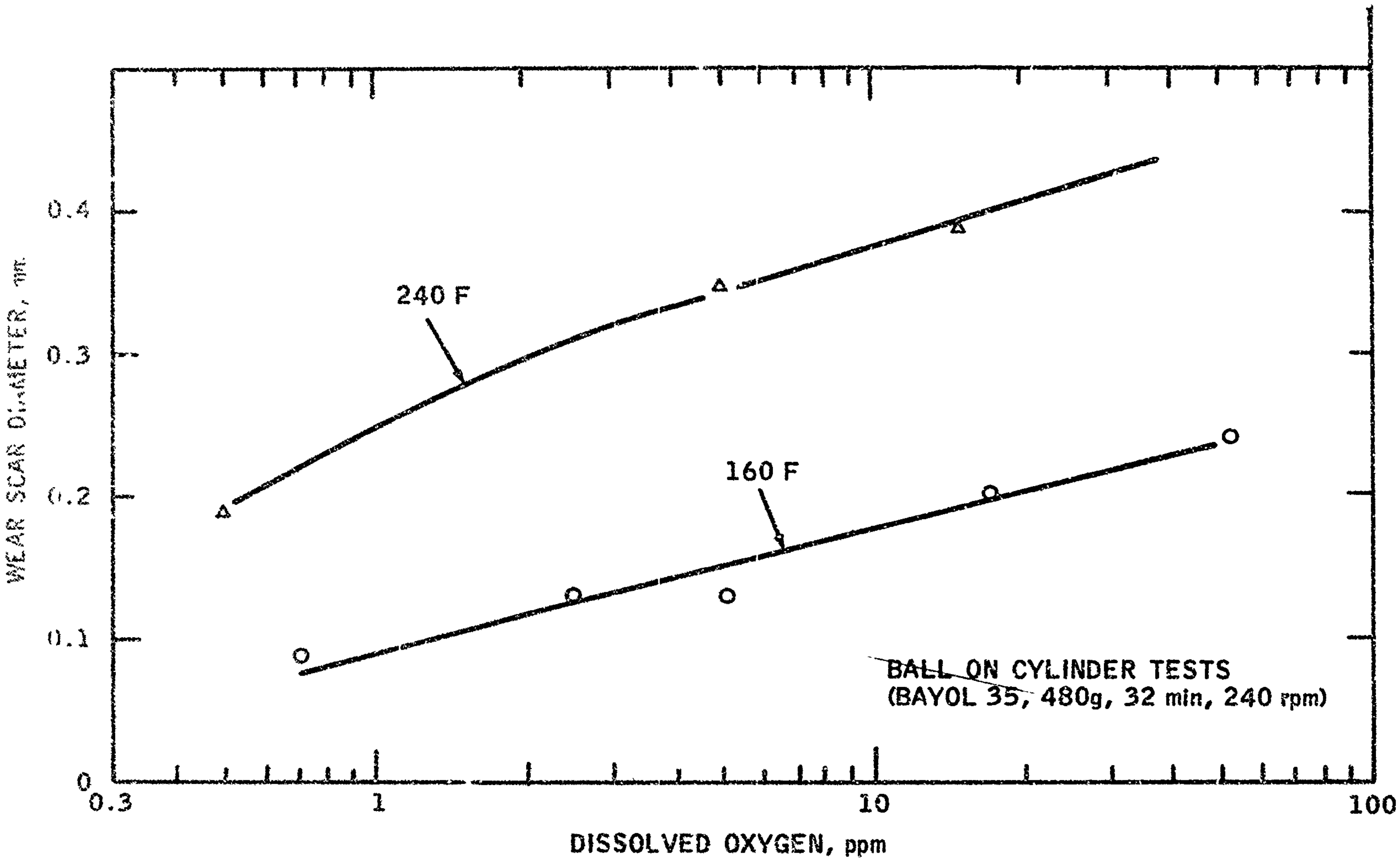


FIGURE 10 - EFFECT OF TEMPERATURE ON WEAR OF BAYOL 35

TABLE 4

EFFECT OF OXYGEN ON WEAR

Ball-On-Cylinder Tests

(240F, 480g, 32 min, 240 rpm)

Atmosphere	Dissolved O_2, ppm	Coefficient of Friction	Wear Scar Diameter, mm
Argon (0.005% O_2)	0.4	0.11	0.29
2.2% O_2	6.3	0.12*	0.45
6.5% O_2	19	0.40*	0.49
Air	59	*	0.55

* Friction trace erratic.

3. Vickers Vane Pump Tests

Vickers vane pump tests were also run at higher temperatures on several commercial fuels in a nitrogen atmosphere. The test data are shown in Table 5. Since the viscosity of the fuels is considerably reduced at these higher temperatures, the pressure could only be maintained at 150 psig or lower due to the excessive internal leakage. The severity of the test depends on both load and fuel viscosity. It may be expressed numerically by a dimensionless group, $\frac{\mu N}{P}$, where μ is the fuel viscosity, N is rotation speed of the pump, and P is the pressure. The pressure is equivalent to the load to press the vanes against the ring. The values of $\frac{\mu N}{P}$, were estimated to be 1.82×10^{-6} with Bayol 35 and 1.10×10^{-6} with PW-523 at the lower temperature of 90F and 350 psig under which conditions very severe wear were observed. The values of $\frac{\mu N}{P}$, for this series of tests, as shown in Table 5, were close to the above values, indicating that the severity of these tests might be similar to those at the low temperatures, despite the difference in pressure. Therefore, these test conditions evaluate the effect of temperature per se, apart from its effect on viscosity.

The results confirm that wear can be reduced to a very low level in an inert atmosphere even at a rather high temperature. This may lead to a practical way to solve the lubricity problem of jet fuels in the field. Tests in dry air and in wet air are under way to investigate the effect of humidity and oxygen.

TABLE 5

VICKERS VANE PUMP TESTS (IN N_2 ATMOSPHERE)

Bayol 35		PW-523		JP-5		RAF-176-64	RAF-173-61	
240	300	240	300	240	300	240	240	300
0.6	0.43	0.4[illegible]	0.33	0.46	0.35	0.44	0.6	0.44
150	110	148	90	125	100	145	125	110
1.16	1.13	0.9	1.06	1.07	0.98	0.88	140	1.16
0.49	0.23	0.42	0.3	0.30	0.23	0.47	0.27	0.23
24	13	23	17	17	13	26	15	13
1	1	1	0	2	5	1	1	1
23	42	78	59	64	74	63	17	6
20	24	17	4	21	20	21	21	23
31	74	24	27	19	22	26	34	26
12	8	15	13	19	16	10	11	11
7	12	12	12	10	13	18	9	9

[illegible]merfeld No $= \frac{(\text{Vis})\ (\text{rpm})}{(\text{Pressure})}$, (Dimensionless)

III. MECHANISM STUDIES

The data presented so far show a number of puzzling effects and unusual interactions. Particularly, the high wear of methylnaphthalene in the absence of oxygen and water, and the synergistic effect of mixtures of Bayol 35 and methylnaphthalene need explaining. Accordingly, tests are being carried out to learn more about the mechanism by which these effects occur.

A. Effect of Inert Atmosphere

Although it seemed fairly obvious that the difference between air and argon was one of oxygen vs. no oxygen, some four-ball tests were run to see if there was any major difference between three inert gases: argon, nitrogen and carbon dioxide. The results, given in Table 6, indicate that the inert gases are similar if not identical in their effect. Particularly, all three, when dry, gave very high wear with methylnaphthalene and, when wet, gave very low wear.

All subsequent work has therefore been done with argon, which has about the same solubility as oxygen, and can be obtained as 99.995% Ar with essentially no water whatsoever.

B. Effect of Antioxidants

1. Four-Ball Tests

Oxygen obviously has a strong effect on wear, increasing it with Bayol 35 (paraffinic) and decreasing it with methylnaphthalene (aromatic). It also appears that the primary attack of oxygen is on the metal to form FeO_2 and not on the fuel to form oxidation products which then attack the metal. However, to check this, a few four-ball runs were made using two common antioxidants: phenyl-alpha-naphthylamine (PAN) and 4,4'-methylene-bis-(2,6 di-t-butyl phenol), (MDTBP). Both were run at 1% concentration in Bayol 35 and methylnaphthalene. This is far above the usual concentration in jet fuels, but was used to magnify any effects. Runs were made in air and argon, wet and dry.

The results are given in Table 7, but they are not very conclusive. PAN reduces the wear of Bayol 35 in all cases but this is exactly what would be expected from adding a heavy aromatic hydrocarbon, which is what PAN is. The effect seems more probably the effect of PAN's aromaticity rather than its antioxidant character. PAN had no effect on the wear of methylnaphthalene in argon; nor would it be expected to. MDTBP reduced the wear of methylnaphthalene in dry argon; it behaves like water in this respect. But again, this cannot be due to its antioxidant qualities.

The only effects that could be connected in any way with antioxidation are the decrease in wear with Bayol 35 in wet air, and with methylnaphthalene in dry air. Both additives are effective under these conditions.

Further tests are required at lower concentrations to avoid the effects of composition change.

2. Ball-on-Cylinder Tests

Ball-on-cylinder tests were carried out on Bayol 35 containing 0.1% MDTBP, and various contents of dissolved oxygen at 160F and 1000g loads. The results are presented in Table 8 and plotted in Figure 11 along with similar data on Bayol 35 alone, and Bayol 35 containing oleic acid. It is obvious that this

TABLE 6

EFFECT OF INERT ATMOSPHERE

(Four-Ball Wear Tests, 36C, 10kg, 1200 rpm, 15 min)

	Wear Scar Diameter, mm			
	Bayol 35		Methyl Naphthalene	
	Dry	Wet	Dry	Wet
Argon	0.58	0.46	1.78	0.43
Nitrogen	0.72	0.69	1.54	0.41
Carbon Dioxide	0.59	0.42	1.62	0.47
Air	0.56	0.79	0.62	0.43
Oxygen	0.67	0.75	0.48	0.46

TABLE 7

EFFECT OF ANTIOXIDANTS ON WEAR
4-Ball Tests: 1200 rpm, 36C, 10kg, 15 min

		Wear Scar Diameter, mm			
		In Argon		In Air	
Antioxidant	Base Fuel	Dry	Wet	Dry	Wet
None	Bayol 35	0.58	0.46	0.56	0.79
1% PAN*	"	0.42	0.41	0.40	0.46
1% MDTBP**	"	0.52	0.50	0.56	0.59
None	Methyl Naphthalene	1.78	0.43	0.62	0.43
1% PAN	"	1.81	0.41	0.48	0.38
1% MDTBP	"	0.85	0.46	0.46	0.40

* PAN = Phenyl-alpha-naphthylamine

** MDTBP = 4,4'-methylene-bis-(2,6 di-t-butyl phenol)

TABLE 8

EFFECTIVENESS OF ANTIOXIDANT

0.1% MDTBP in Bayol 35

(Ball-on-Cylinder Tests - 160F, 1000g, 240 rpm)

Atmosphere	ppm O_2	Coefficient of Friction	Wear Scar Diameter, mm
Argon	0.4	0.14	0.22
2% O_2 in Argon	6	0.22	0.29
7.3% O_2 in Argon	21	0.22	0.38
Air	59	*	0.65

* Erratically high.

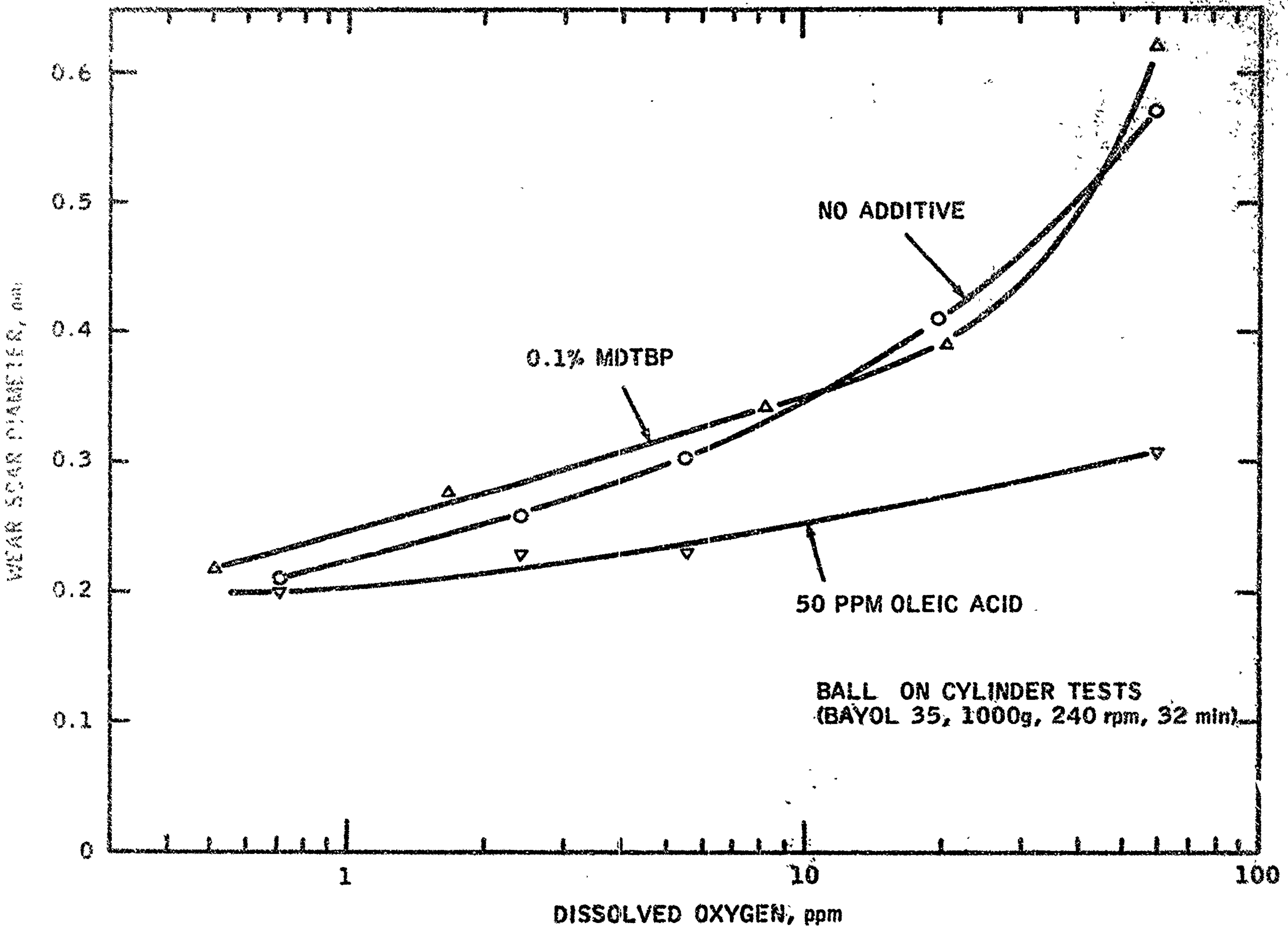


FIGURE 11 - EFFECT OF OLEIC ACID AND ANTI-OXIDANT MDTBP ON WEAR - BALL-ON-CYLINDER TEST

antioxidant is ineffective in improving the lubricity of the base fuel. This confirms that the oxygen attack is at the metal surface rather than oxidation of the fuel.

C. Effect of Oleic Acid

In the previous Report, it was found that oleic acid was an effective antiwear additive in the presence of oxygen but not in its absence. (See Figure 11.) This suggested that oleic acid might be working by preventing corrosion rather than by any inherent lubricity property. To learn more about this, oleic acid was run under a variety of conditions in the four-ball wear tester.

Blends of 50 ppm oleic acid in both Bayol 35 and methylnaphthalene were run in both argon and air, both wet and dry. Results are given in Table 9 and in Figures 12, 13 and 14.

It appears that oleic acid is most effective in reducing corrosive wear and has little effect elsewhere. In Bayol 35 in air, oleic acid cut wear in half as shown in Figure 12. Essentially, it reduced the WSD to a low level of about 0.37 mm regardless of the humidity. One can speculate that oleic acid is functioning as a corrosion inhibitor, forming a protective film on the surface that resists oxygen attack.

In argon, oleic acid again maintained wear at a low level. As shown in Figure 13, it reduced the relatively high wear in dry argon, but did not further reduce the lower wear in wet argon.

In methylnaphthalene, oleic acid is completely ineffective. It did not reduce the very high wear in dry argon, and it had only minor effects in the other cases, where the wear was already low. This is perhaps not too surprising for it has been reported in the literature that organic acids work best when oxide films are present.

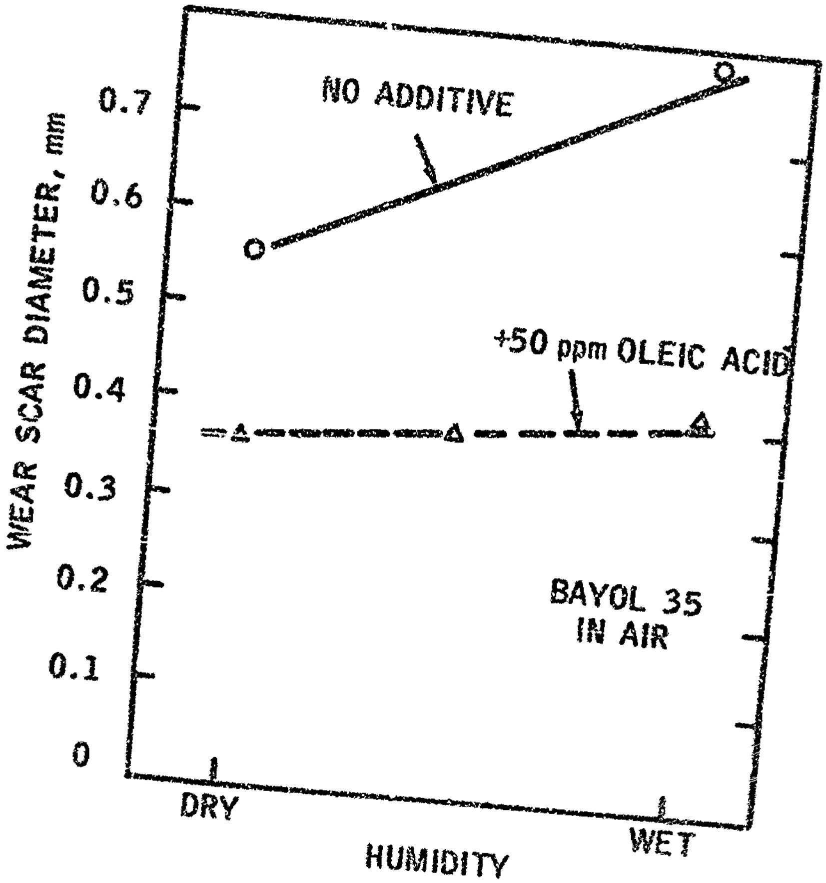
Tests of this nature will be carried out on other lubricity additives and in greater detail.

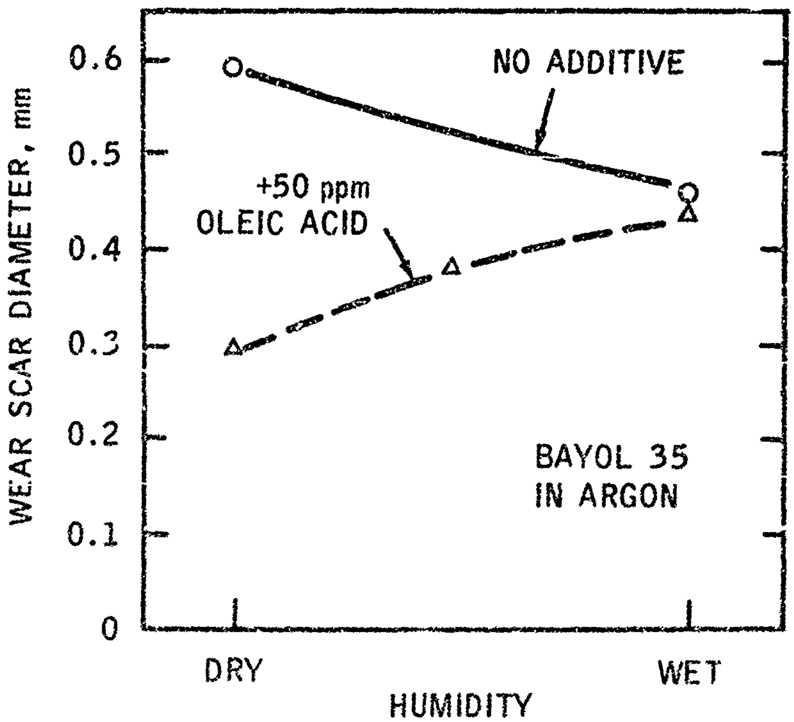
TABLE 9

EFFECT OF OLEIC ACID ON WEAR

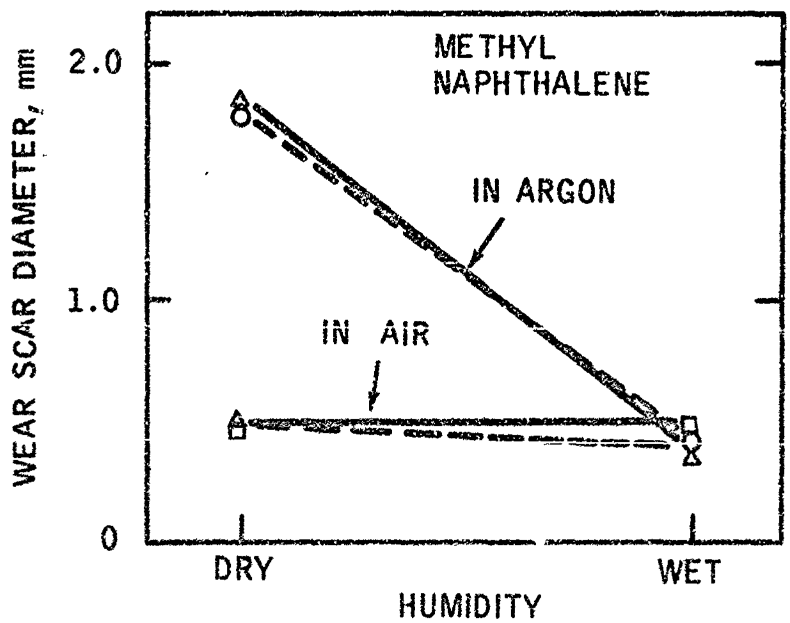
4-Ball Wear Tests: 1200 rpm, 36C, 10 Kg, 15 min

ppm Oleic Acid	Atmosphere	Wear Scar Diameter, mm					
		Bayol 35			Me Naphthalene		
		Dry	Moist	Wet	Dry	Moist	Wet
0	Argon	0.58	---	0.46	1.78	---	0.43
50	Argon	0.30	0.38	0.44	1.81	1.76	0.36
0	Air	0.56	---	0.79	0.48	---	0.46
50	Air	0.37	0.38	0.42	0.53	0.47	0.38


NO ADDITIVE
+50 ppm OLEIC ACID
BAYOL 35
IN AIR
WEAR SCAR DIAMETER, mm
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
DRY
WET
HUMIDITY



WEAR SCAR DIAMETER, mm
0.6
0.5
0.4
0.3
0.2
0.1
0
NO ADDITIVE
+50 ppm
OLEIC ACID
BAYOL 35
IN ARGON
DRY
WET
HUMIDITY


METHYL
NAPHTHALENE
IN ARGON
IN AIR
2.0
1.0
0
WEAR SCAR DIAMETER, mm
DRY
WET
HUMIDITY

IV. FUTURE WORK

It is evident that at least four factors are important in lubricity: hydrocarbon composition, atmosphere, temperature, and polar additives. A fifth factor--metallurgy of the rubbing surfaces--can certainly be expected to be important, too.

It is also evident that there is a complex interaction between these variables. Mixtures of paraffins and heavy aromatics give less wear than either pure component; oxygen increases the wear of paraffins but decreases the wear of heavy aromatics; polar additives decrease wear in air but not in argon; high temperature cause more wear and friction in air but not in argon.

Future work will therefore concentrate on these interactions, trying to find the underlying causes.

- A large number of hydrocarbons will be evaluated, both in the pure state and as mixtures, to observe any unusual effects and to get a pattern correlating molecular type with lubricity. These tests will be carried out in different atmospheres, as has already been started.

- Various lubricity additives, corrosion inhibitors, and other jet fuel additives will be examined in different base stocks, different atmospheres, and different temperatures.

- The effect of fuel oxidation will also be examined. This appears to be a source of some confusion in the literature.

- Tests will be run in the Vickers vane pump rig at higher temperature and also in different atmosphere.

- The effect of metallurgy will be examined using the four-ball tester because of the ease of obtaining test specimens in this machine. This work will not begin until March when a new four-ball machine becomes available.